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Ball Lightning With an Oxide Cover and Metallic or Metalloid Powder Core

V. L. Bychkov

Physical department, M.V. Lomonosov MSU

BL observations

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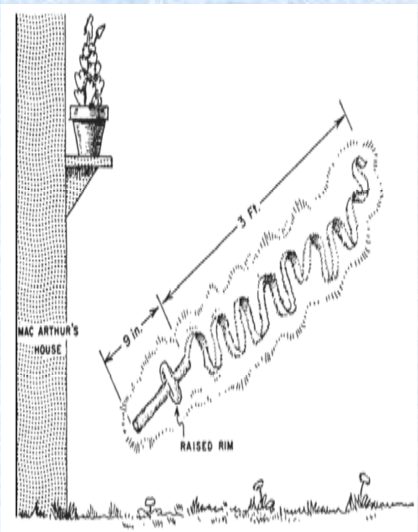
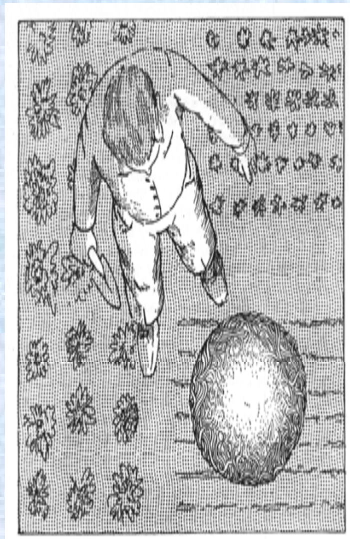
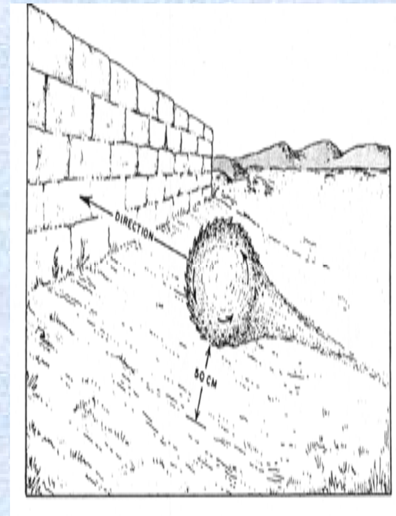
W. R. Corliss Unusual Natural Phenomena. Gramsey books. NY. 1995.



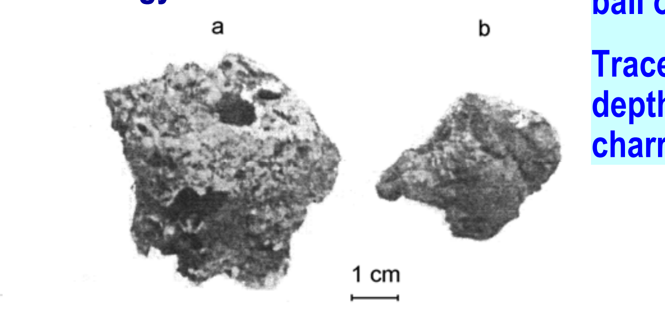
Ball lightning with a curious ribbon attached





Dmitriev ZTF
1981. V.51. N. 12. P. 2567-2572.

Energy estimate 10 ^{9} J



Khabarovsk 1978. 24 August 23.20 h. Strong rain without lightning. A ball of 1.5 m in a diameter.

Trace: 1.5 m in a diameter and depth 20-25 cm – the soil became charred and melted.

Observations

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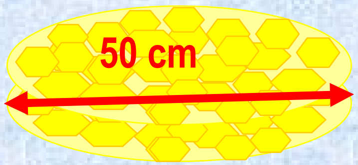
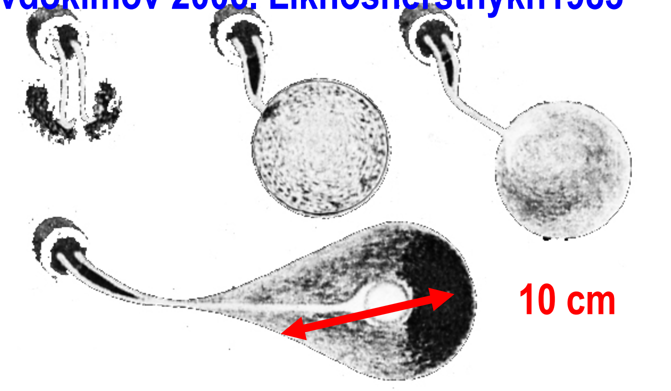
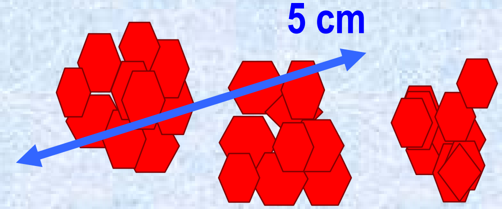
Belokon 2006

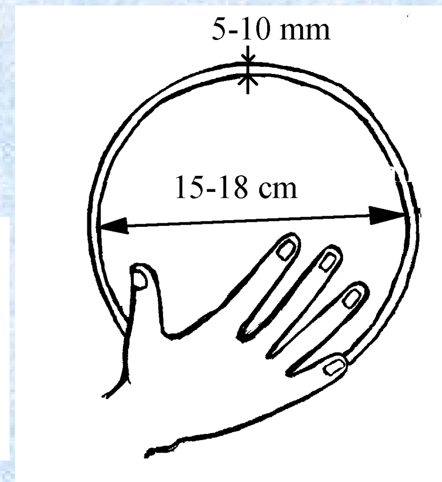


Evdokimov 2006, Likhosherstnykh1983

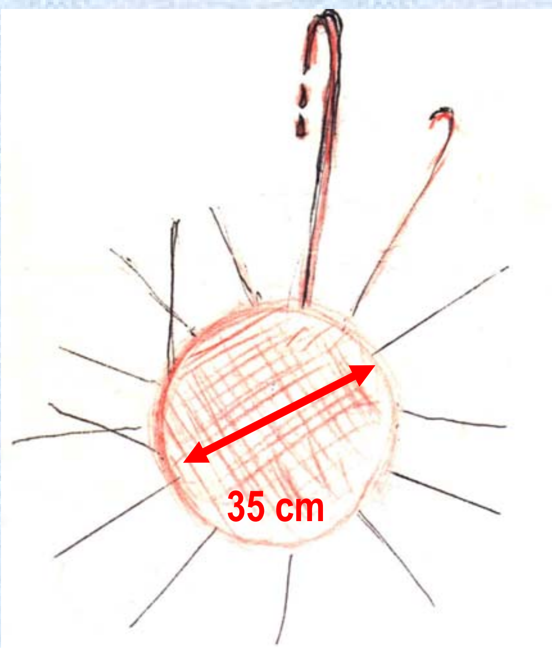


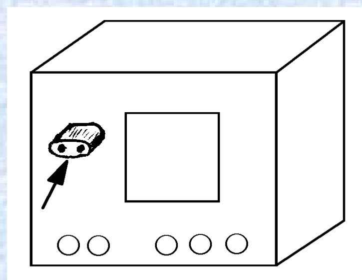
Timoshuk1990



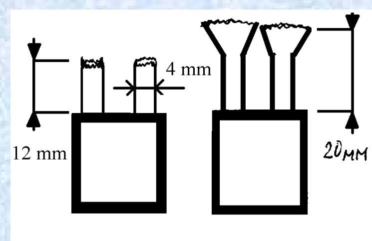


Dubrovskyi 2003

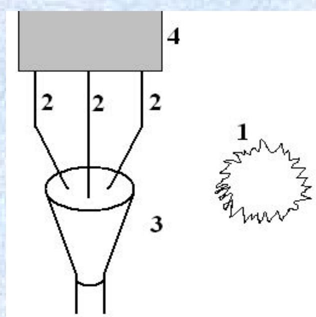


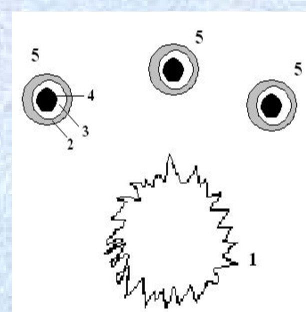


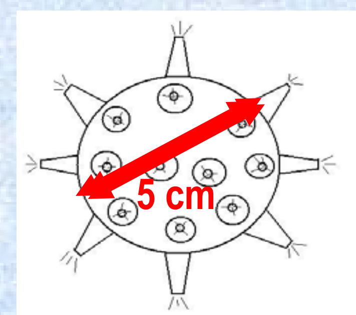
Medvedev 2004



Sherbak 2004







Collection and analysis of observations MSU

Traces left by BL indicate possibility of thermal and electric impact of BL. New accent in these investigations is more detailed analysis of residuals and traces, which allows estimating BL energy, electrical and mechanical properties. In this connection it is necessary to mark new investigations of a joint team A.Nikitin et. al. that analyzed window glass properties after it was impacted by BL.

To the right is a hole in the glass, to the left is the disc that had fallen out the hole. Disc (hole) axes sizes are 8.2 and 7.6 cm.

Analysis of large sized BL and UFO events from BL features point of view indicates that some number of UFO objects represent large BL. Analysis of long lived luminous object (LO) appearance in earthquakes, volcanoes and geotectonic processes shows that a part of BL can have origination in Earth processes, between charged layers of rocks.

No final conclusion on mechanism of the hole appearance

Collection and analysis of observations

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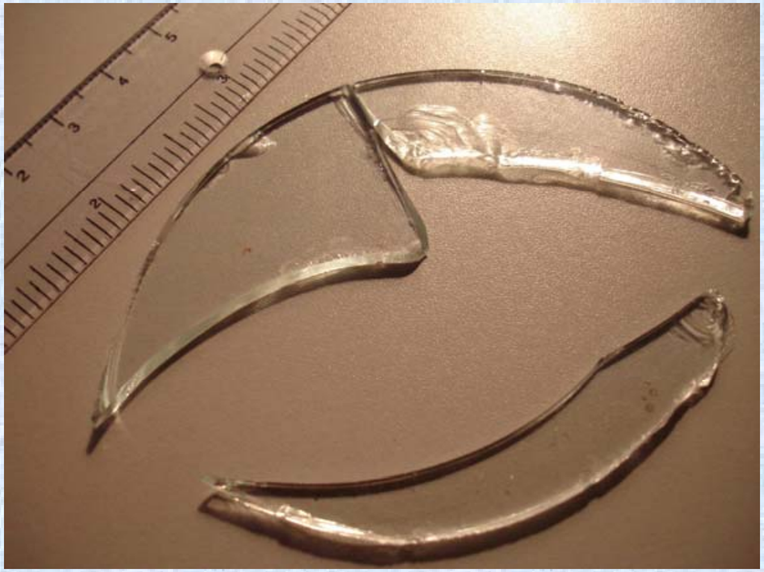

Observer N.Babaeva, Physicist, Ph.D.. Iowa 3.08.2007.

The hole appeared after a flash of a linear lightning

The glass pieces have not been analyzed yet (2007-2010)

BL energy

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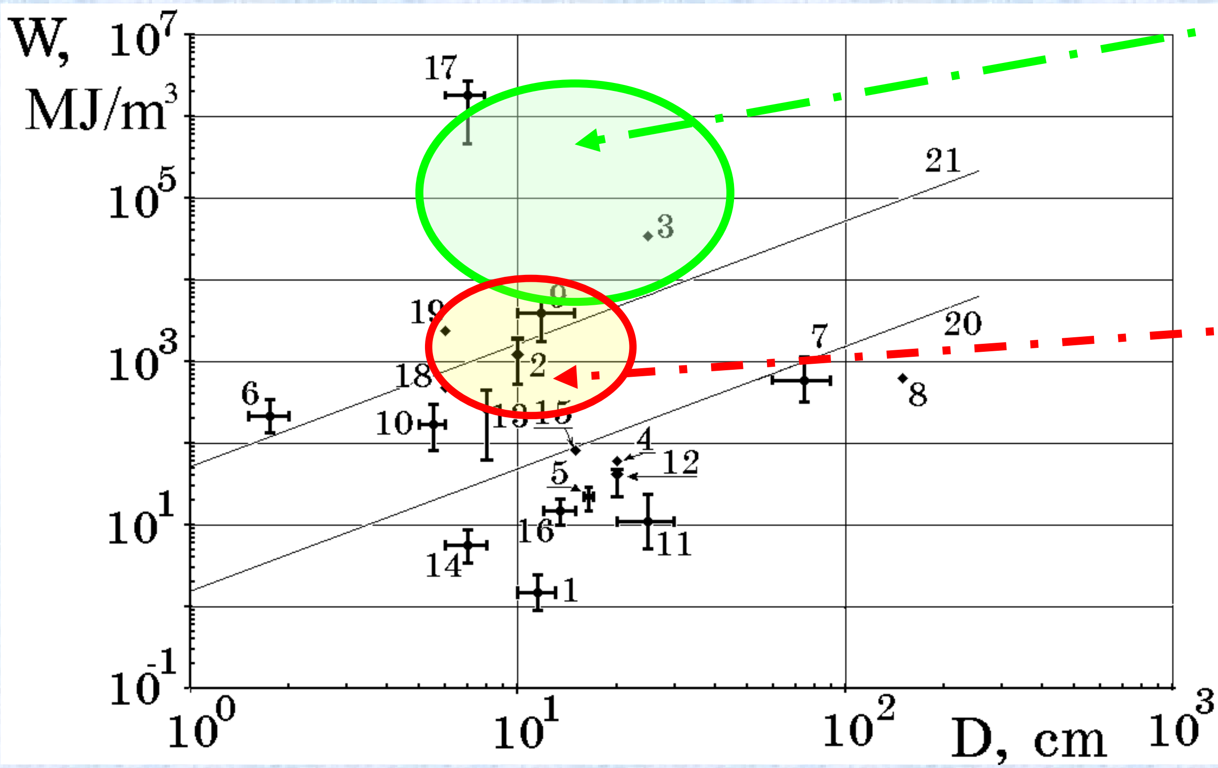

3, 9 and 17 estimates of observations with water heating

$10^4 < W < 2 \cdot 10^6$ MJ/m^3

6-19 Energy density $10^2 < W < 5 \cdot 10^3$ Mj/m^3 .

1- (Grigor'ev 1990); 2-5- (Egely 1987), 6-(Stenhoff 1999);. 7-(Singer 1971; Kozlov 1978); 8-(Dmitriev et al 1981); 9-(Goodlet case, Barry 1980);10-13 -(Stakhanov1979); 14,17 -(Imianitov & Tikhii 1980); 15-(Barry 1980; Singer 1971); 16-(Wittman 1971); 18 -(Barry 1980); 19 - (Bychkov et al 1996);

Collection and analysis of observations

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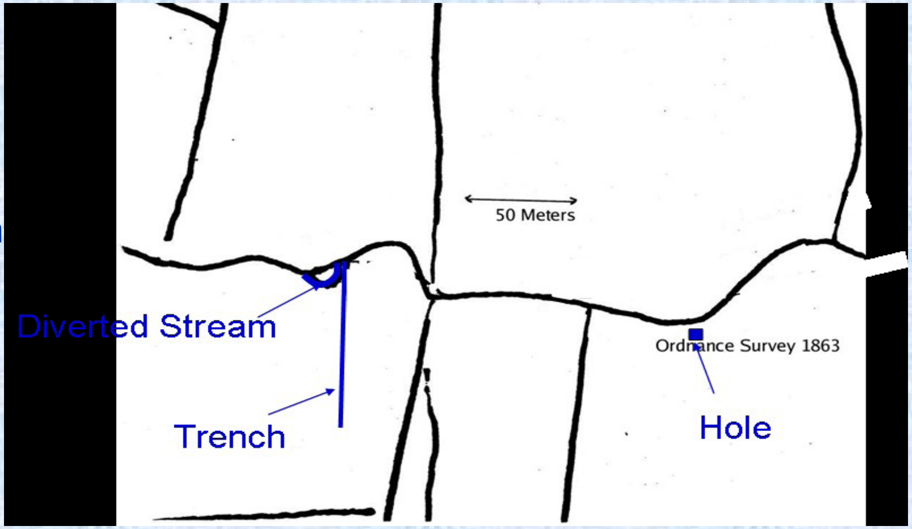
J. Pace VanDevender (USA) [2008, Kaliningrad] : results of field researches of the event which has occurred on August, 6th, 1868 in County Donegal in Ireland.

Witness Michael Fitzgerald during walk has noticed a red fiery sphere about 60 cm in diameter, slowly moving in air. "After passing the crown of the ridge … it descended gradually into the valley, keeping all the way about the same distance from the surface of the land, until it reached the stream" (coast) in 90 meters from a place where an observer was standing. " It then struck the land and reappeared in about a minute, drifted along the surface for about 60 m and again disappeared into the boggy soil, reappearing about 100 m further down the stream; again it moved along the surface, and again sunk, this time into the brow of the stream, which it flew across and finally lodged in the opposite brow, leaving a hole in the peat bank, where it buried itself…I… found a hole about 6 m, where it first touched the land, with the only pure peat turned out on the lea as if it had been cut out with a huge knife. This was one minutes work…It next made a drain about 100 m in length and 1.2 m deep, afterwards ploughing up the surface about 30 cm deep, and again tearing away the bank of the stream about 25 m in length and 1.5 m deep, and then hurling the immense mass into the bed of the stream, it flew into the opposite peaty brink. From its first appearance till it buried itself could not have been more than 20 minutes … It appeared at first to be a bright red globular ball of fire, about 60 cm in diameter, but its bulk became rapidly less, particularly after each dip in the soil, so that it appeared not more than 8 cm in diameter when it finally disappeared".

The brigade of researchers has found out, what even later 137 years after the incident on the earth have remained traces of the ditches made by BL. Authors estimated the work spent by BL in 4·10^7 J and considered that the ditch has been pressed through in the earth by a microscopic black hole in weight from 2·10^4 to 10^6 kg, which "magnetically levitated by a large electromagnetic field".



Theories and analysis of observations

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Unusual BL features

1. Capability of drag of bodies (human) (Likhosherstnykh),
2. Displacement of heavy metallic sheets (100 kg) [Nikolaev] ,
3. lifting and drag of heavy (10^4 kg) roofs (Egely)
4. Pulling out of rivets from shoes (Likhosherstnykh).

Egeli: $R_{bl}=1$ m Velocity BL $V1 \sim 2$ m/s $M_{roof}=10^4$ kg

Momentum conservation $M_{bl} \cdot V1 = (M_{bl}+M_{roof}) \cdot V2$

$V2 \ll V1$

$M_{bl} \sim M_{roof} \cdot (V2/V1)$ $V2/V1 \sim 0.1$

$M_{bl} \sim 10^3$ kg $\rho \sim 250$ kg/m^3

BL – HEAVY SUBJECT

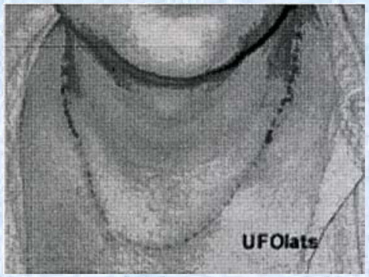
Unusual BL features

Cases connected with thermal effect of BL

Effect	Number of cases	Percent, %
Burns, fires, melts [Stakhanov]	Total number of cases in the collection 1293 Number of cases described in [Stakhanov] 120	4.9 21
Body burns, fires [Egeli]	383	17
Melts, fires [Abrahamson]	58	28
Burns, fires, water heating [Grigoriev]	281	25

Disappearance of golden bracelets and rings from people hands [Imyanitov, Likhosherstnykh].

There is a shortage of information and detailed observations. There is an information absence about psychological state of observers: observer can feel short time pain during electrical or thermal BL impact on metallic subjects (rings and bracelets). In psychological stress they put off these subjects from their hands, and later forget about their own actions. The killed girl [Likhosherstnykh] at supposed contact with BL got a ring burn on a place of a ring, but the ring had disappeared.



Last known case http://www.ufo.lv (ufolats). 10.06.06

O. Andreev , 42 y.o., Rizhskyi bay, near Yankimeri. About 16.00 pm.

After bathing he was going out on the shoe. Suddenly (by his wife' words) near him flew bright yellow-orange ball, of tennis ball size. Strong crash sounded. Andreev fell down with face uin the sand. He did not loose consciousness, but was strongly inhibited, consciousness was scattered. When he was turned over his face was covered with soot.

People bathing in the gult at that time felt noticeble current shock.

He was hospitalized. Before the event he haad a golden chain on this neck, which had dissappeared after this. A finger thick trace of burn left on his body. (On the photo one can see thin trace on his body widening near near his neck.) He was in the shock state with injuries of heels and genitals. After two days he returned home without without serious consequences.

Presented example puts forward more questions than answers

Experiments on BL analogues modeling MSU

Modeling of material structures in different plasma conditions with combustion and plasma assisted combustion. These directions usually can not be separated. To these directions we can attribute works of many teams.

In the team of S. Emelin, S-Petersburg University, the accent was made on processes of combustion of a material with complex features appearing in gas discharge plasma at its interaction with a material of electrodes, erosion material and some insert. Here were obtained fireballs (FB) with size of ~ 10 cm and visual time of several fractions of a second.

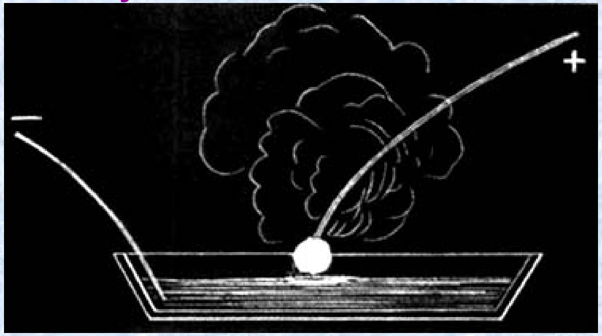
Volumetric discharge with carbon electrodes accompanied with combustion and its afterglow

Experiments on BL analogues modeling МГУ

R. Kuz'min, B Shvilkin. MSU, combusting mixtures were specially prepared for producing of spherical and torus structures at discharge realization. Sizes of their objects reached 5-6 cm and lifetime 2-3 s. They were created at an explosion of a thin metallic wire. There was a hole for going out of explosion products. At last stage objects transformed to vortical rings.

Experiments on BL analogues modeling MSU

New scientific direction which appeared in works of G.D. Shabanov team in Nuclear physics institute, Gatchina (Leningrad district) "Gatchinskyi discharge". Spherical object with a lifetime of 1 s , and sizes 12-14 cm. Experiments are also undertaken by S. Emelin and A. Nikitin teams in Russia and by Fussman team in Germany.



Plantee, 1890

G. Shabanov. 2002

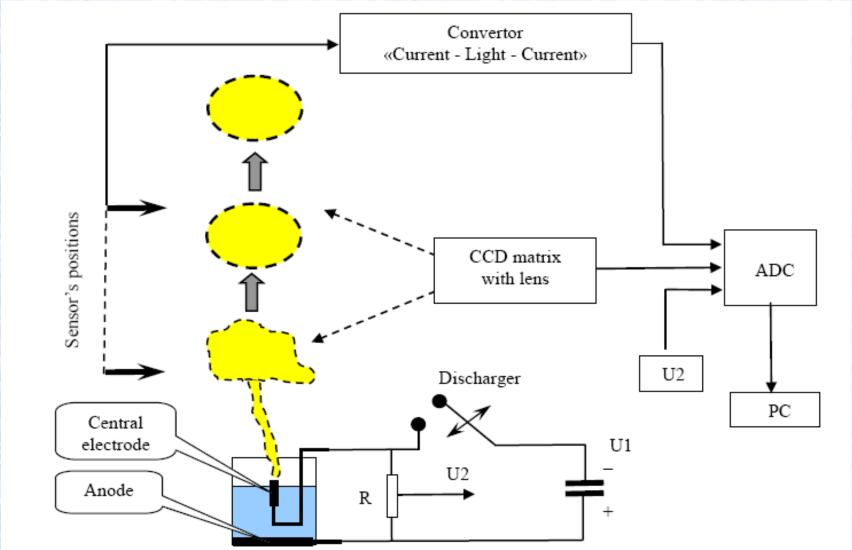


Figure1 - Block-scheme of experimental set-up

Experiments on BL analogues modeling

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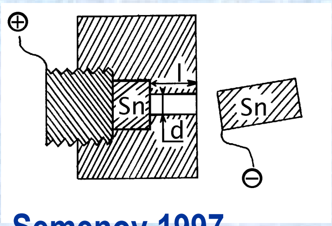
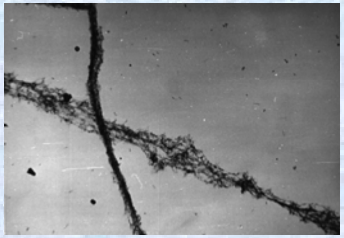
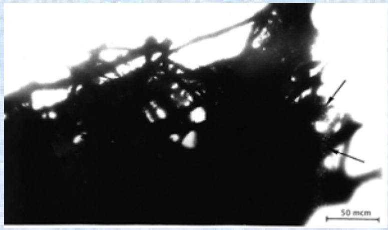
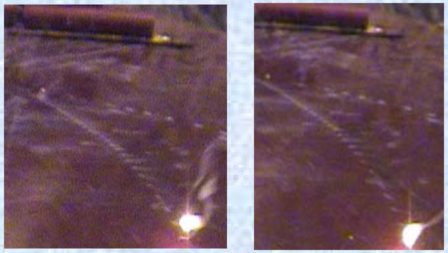
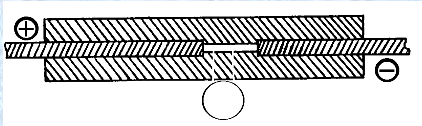




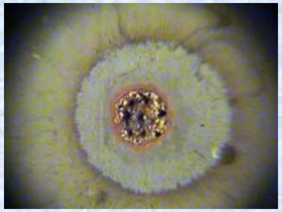


Emelin 2005

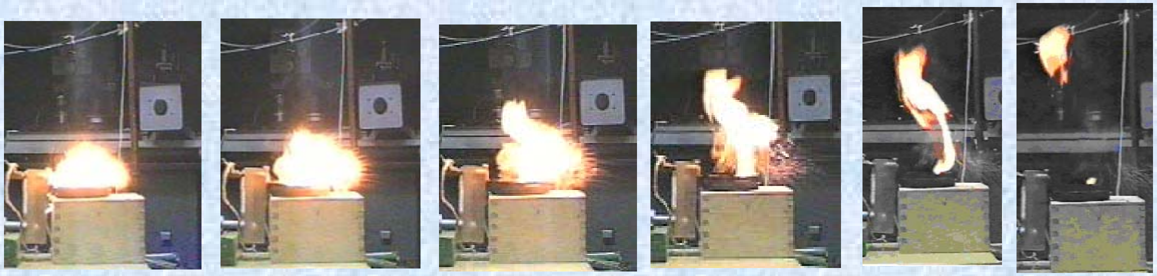


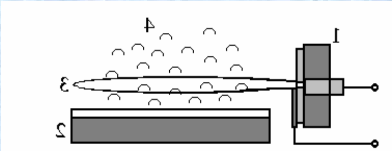


Emelin, Semenov 1997

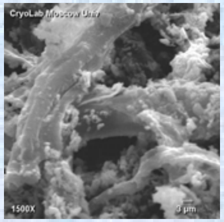


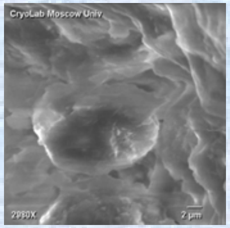
Emelin 1997





Bychkov, Timofeev 2002-2004





t~2 s, R~2 cm

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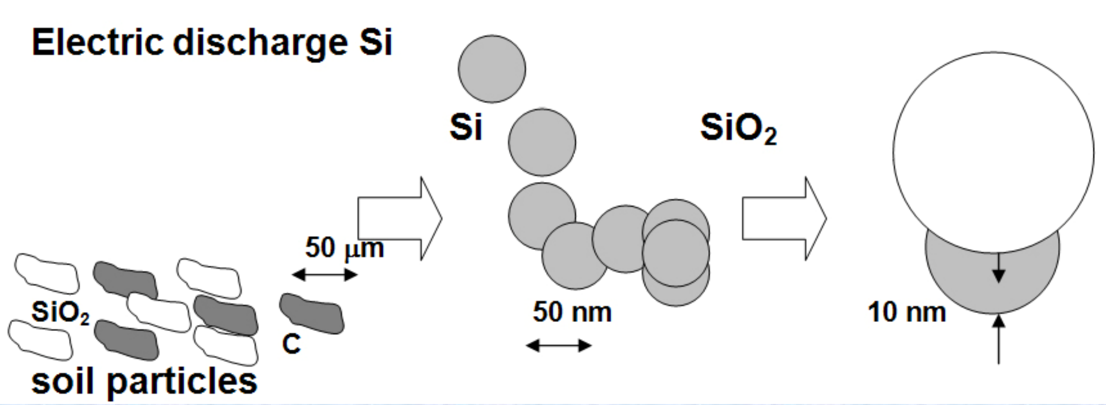
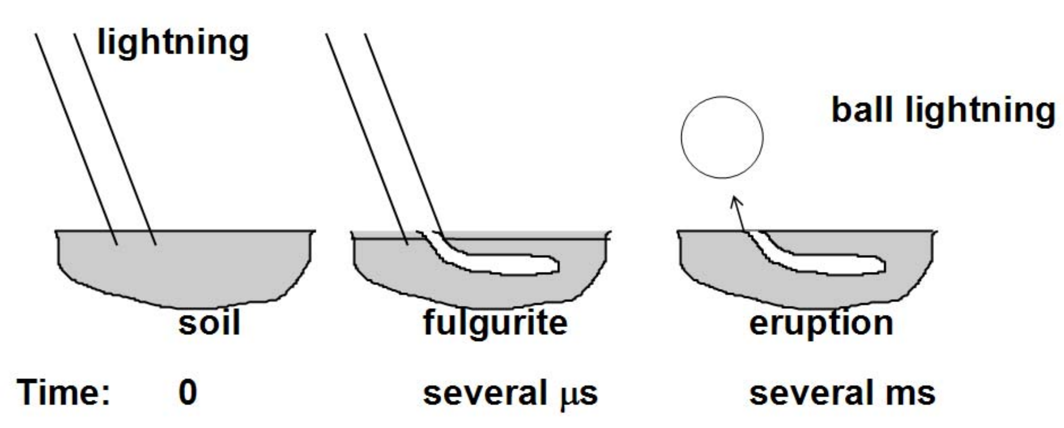
BL Abrahamson theory

Abrahamson J., Dennis J. Nature 2000, 403, 519-521





Experiments on BL analogues modeling

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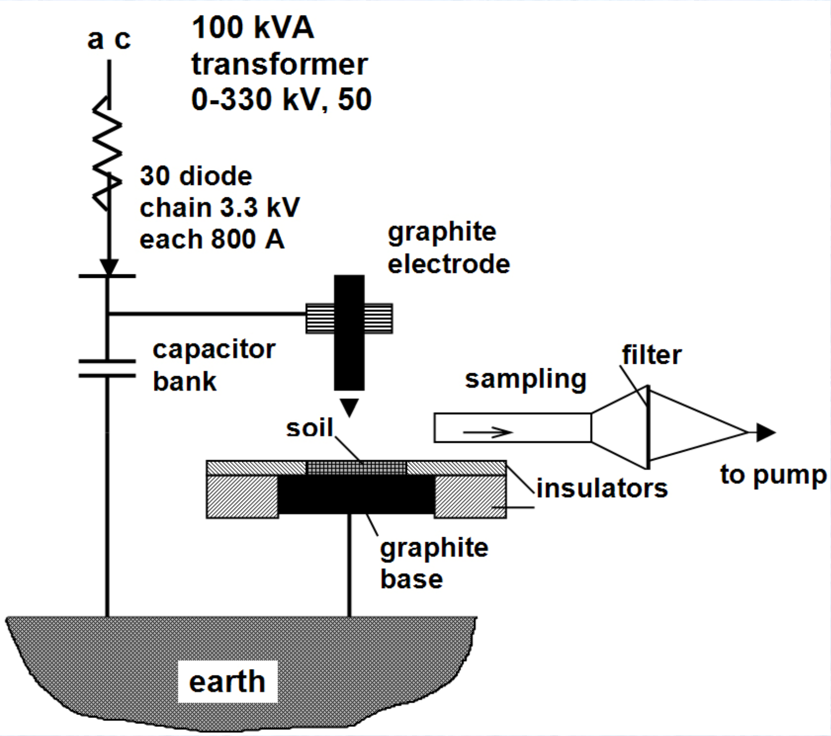

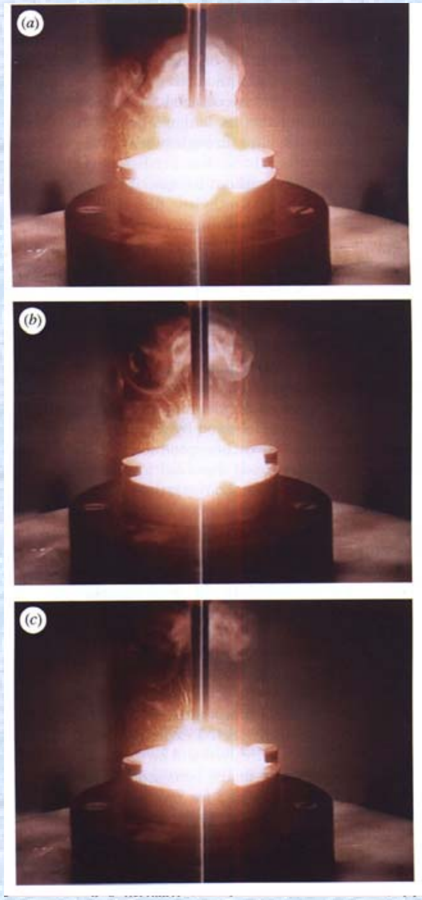

Abrahamson J. Phil. trans. Roy. Soc.2002. P.61-88

Experiments on BL analogues modeling

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Lazarouk S. K., Dolbik A. V., Labunov V. A., and Borisenko V. E. Spherical Plasmoids Formed upon the Combustion and Explosion of Nanostructured Hydrated Silicon. JETP Letters, 2006, Vol. 84, No. 11, pp. 581–584.

Ball lightning produced by thermal ignition of 100 µm thick 1 cm in diameter porous silicon filled with KNO_3: a) as formed, b) 0.1 s after formation, c) 0.3 s after formation, d) 0.5 s after formation, e) 0.7 s after formation, f) 1 s after formation.

Experiments on BL analogues modeling

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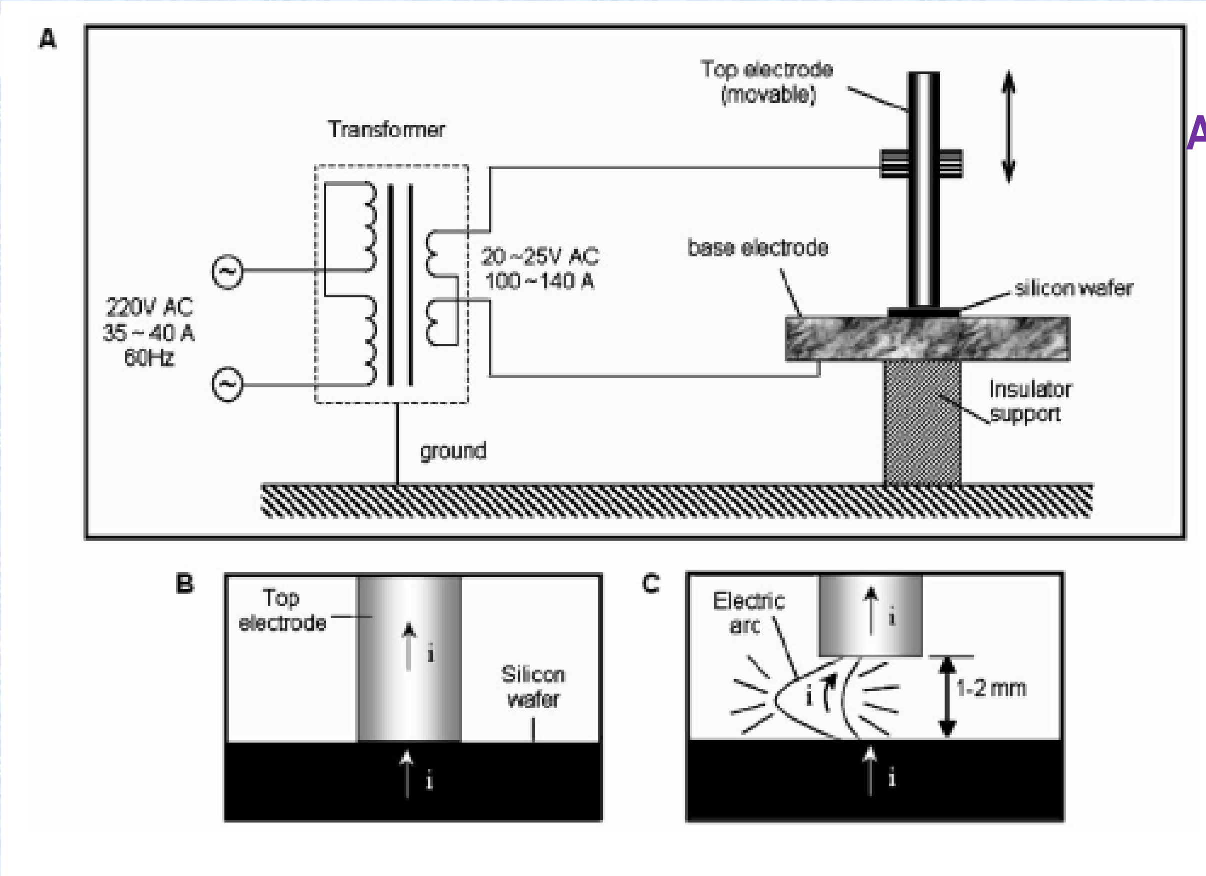

A. Pavao and G. Paiva, Brazil, obtained long lived fire balls by locating of doped silicon samples 0.3 mm thick between electrodes. At departing of electrodes there was realized an electric arc from which luminescent ball of 3-4 cm size and 5 s lifetime appeared..

FIG. 1. (a) Experimental arrangement showing the power supply, electrode geometry and the Si wafer. (b) The top electrode is lowered until it touches the Si piece and closes the circuit. (c) The top electrode is raised up to a distance of 1 to 2 mm, approximately. An electrical arc is formed during this upraising movement. Hot-glowing fragments and, eventually, ball-lightning-like luminous balls fly away in all directions.

Experiments on BL analogues modeling

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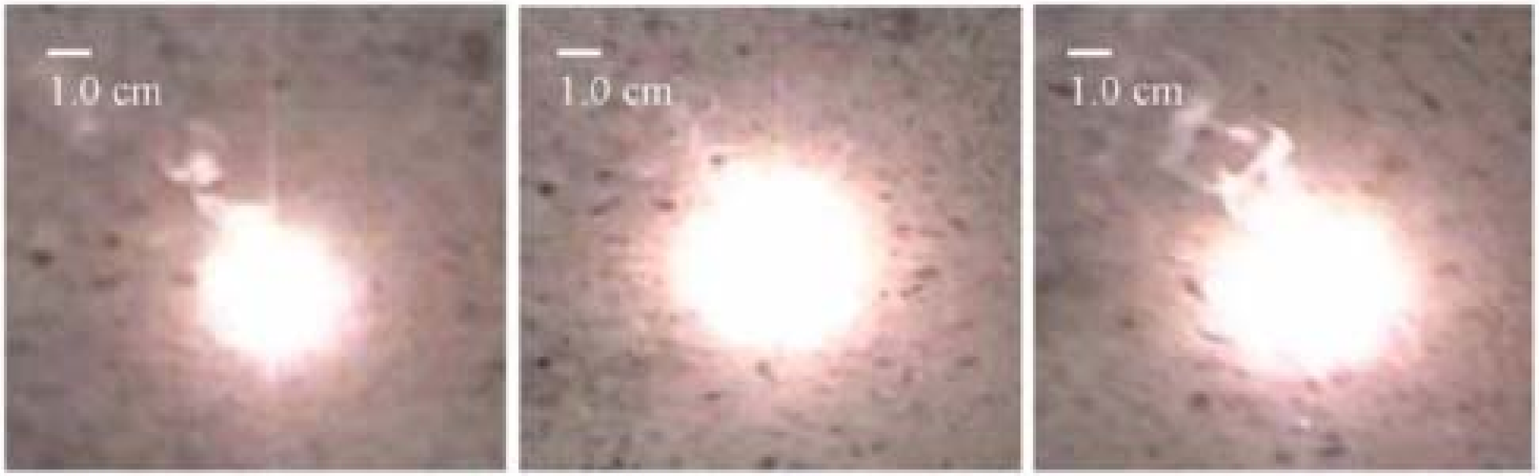

FIG. 4 (color online). Successive video frames showing a luminous ball leaving spiraling smoke trails above it. Time interval between the frames is 80 ms. See also supplementary video 4 [19].

In structures Si + H, Si + O --- oxidizing with release of energy is analogous to explosives

$Fe_2O_3+2Al=Al_2O_3+2Fe+198$ ccal

Experiments on BL analogues modeling

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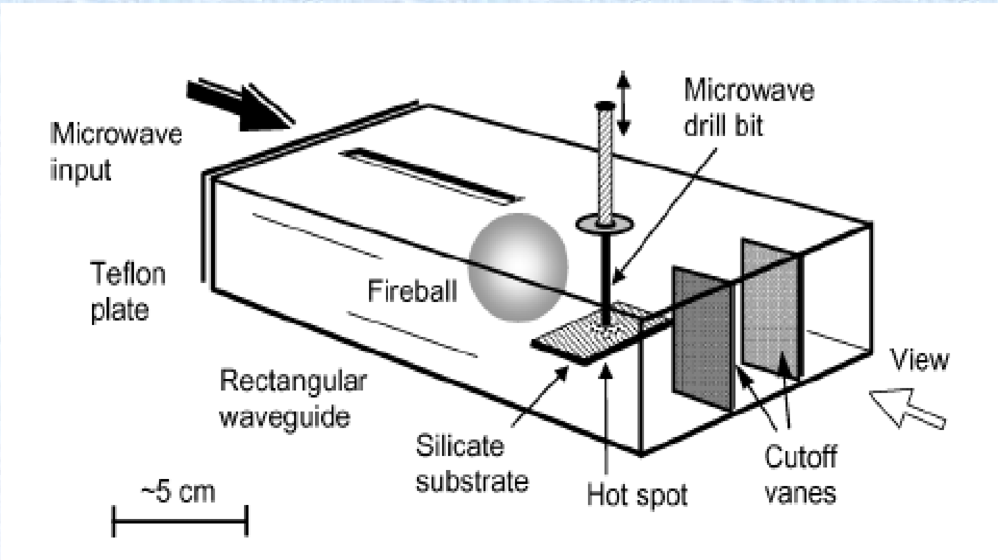

FIG. 2. The experimental setup consists of a waveguide fed by a 0.6 kW magnetron. The microwave energy is concentrated by the microwave-drill bit to form a molten hot spot in the substrate material from which the fireball evolves. A mirror made of vanes and the slot along the waveguide enable a direct view into the cavity.

Experiments E. Jerby and V. Dikhtyar, from Tel –Aviv university on generation of luminescent balls under impact of concentrated MW beam to silicon and other materials

BL analogues modeling

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Abrahamson $SiO_2 + 2C \rightarrow Si + 2CO$ $Si + O_2 \rightarrow SiO_2$

Stephan $Si(l) + O_2(g) \rightarrow SiO_2(l)$ $2Si(l) + O_2(g) \rightarrow 2SiO\ (g)$

$$SiO_2 + 2SiC \rightarrow 3Si + 2CO$$

Si data $Si + C + O_2 \rightarrow SiC + SiO(g)$ $Si + C + N_2 \rightarrow Si_3N_4 + C \rightarrow SiC + N_2$

$SiO_2 + 3C \rightarrow SiC + 2CO$ **carbonaceous silicon**

$SiO_2 + C \rightarrow SiO(g) + CO_2(g)$ **T>1000 °C**

$SiO_2 + 3Si \rightarrow 2SiO(g)$ **T=1100-1300 °C**

$$SiO_2 + H_2 \rightarrow SiO(g) + H_2O(g)$$

$$SiO_2 + Si \rightarrow SiO$$

Silica W – fibrous silica кремнезем

$$2SiO + O_2 \rightarrow 2SiO_2$$

Obtained in gas discharges at low pressure from a mixture of SiO2 and Si

In water is transformed to methacrylic acid

BL analogues modeling

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Meetings of BL with aircrafts says

that Al and duralumin can be candidates for materials of BL

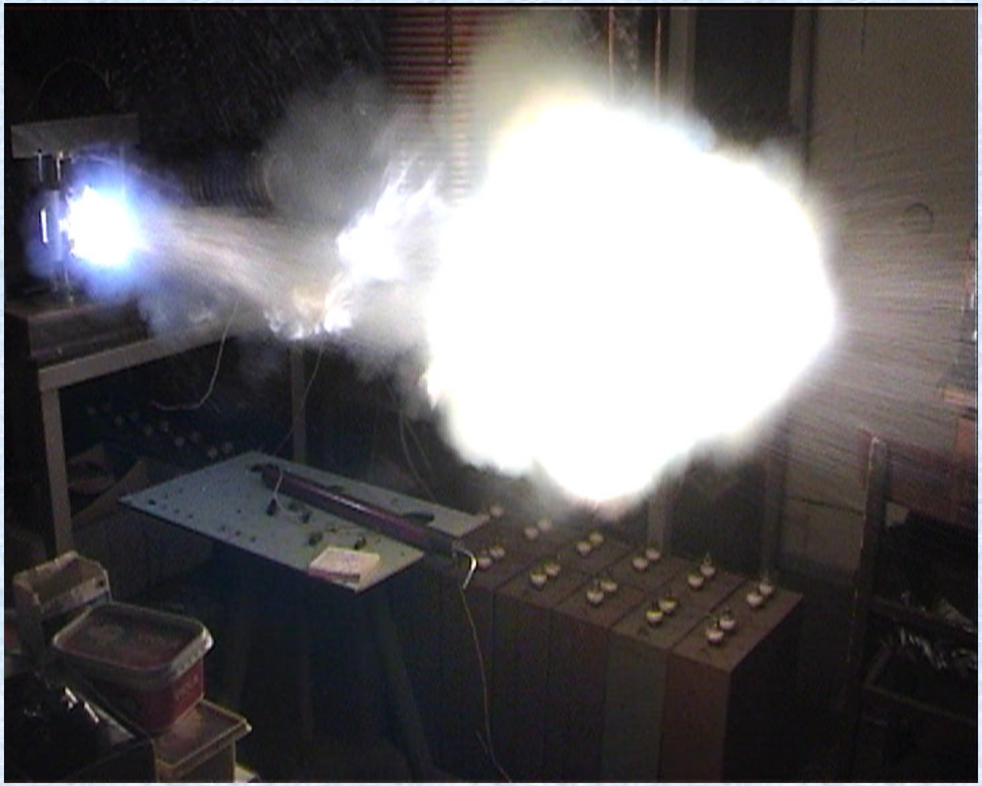
$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

$$4Al(l) + Al_2O_3(l) \rightarrow 3Al_2O(g)$$

$$Al(l) + Al_2O_3(l) \rightarrow 3AlO(g)$$

$$2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2$$

$$2Al + 6H_2O \rightarrow 2Al_2O_3 + 3H_2$$



Experiments with alumina and other metallic powders S. Emelin 2010

Model

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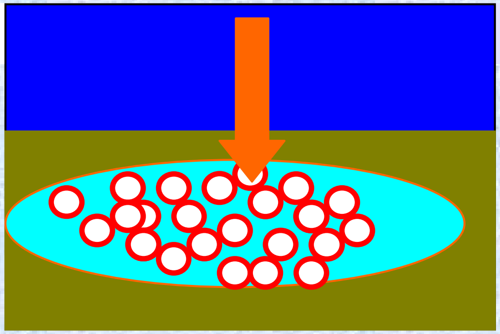


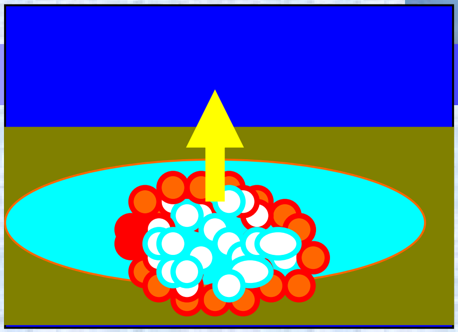
recovery

$$SiO_2 + 2C \rightarrow Si + 2CO$$

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$$

$$SiO_2 + 2H_2 \rightarrow Si + 2H_2O$$

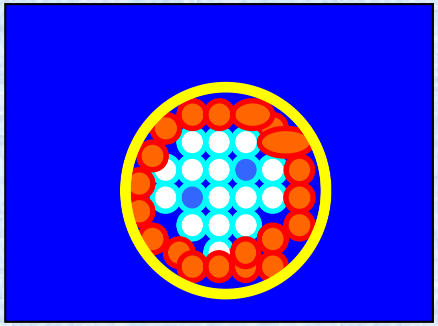
$$Al_2O_3 + 3H_2 \rightarrow 2Al + 3H_2O$$



Formation of oxide cover

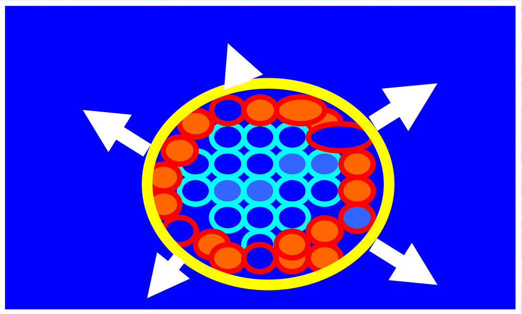
$$Si + O_2 \rightarrow SiO_2 \qquad 2Al + 3O_2 \rightarrow Al_2O_3$$

Bychkov V. 2010



Formation of plasma cover

Appearance in air



Combustion and explosion

$$Si + CO_2, H_2O \rightarrow SiO_2 + \text{products}$$

$$Al + CO_2, H_2O \rightarrow Al_2O_3 + \text{products}$$

$$SiO_2(solid) + Si(solid) \rightarrow 2SiO(gas)$$

$$Al_2O_3(liquid) + 4Al\ (liquid) \rightarrow 3Al_2O(gas)$$

Thank you for attention

BL Theory

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On the basis of proposed model let us make estimations for described above observation case in Khabarovsk city. Let us suppose that in this case ball lightning was created at linear lightning stroke into earth, then it moved over ground. BL explosion took place at initial stage of its existence and all its internal content fell on earth and combusted there. So we consider BL as a ball which radius is 0.75 m and it is filled by hot Si powder.

Chemical energy. **Let us determine the mass of BL substance – Si powder. For this purpose we consider that pieces of slag left on earth consisted of a quartz glass with density ρ = 2.65 ·10^3 kg/m^3, for simplicity of estimates we consider them balls with radius =3 cm. Then 1000 such pieces of SiO2 have weigh ≈ 300 kg and a corresponding mass of Si is m Si ≈ 140 kg. Accepting a radius of the ball lightning (BL) as *R*=0.75 m one obtains a density of BL content as ≈ 80 kg/m^3, i.e. is very low-density material.**

Energy released at its oxidation is

$$W_{ch} = m_{Si} \cdot \Delta Q \qquad (1)$$

where is an oxidation enthalpy of Si, at typical combustion temperature T=2000 K it is ΔQ=8.8 ·10^6 J/kg. So chemical energy released at its combustion was about Wch ≈ 1.2·10^9 J, i.e. is close to estimates of [Dmitriev], given above.

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Process time.

Let us estimate the charge leakage time from the surface of the created object in the soil. Charge leakage equals to a current from the object surface, which in case of a sphere equals to

$$\frac{dQ}{dt} = -\sigma E \cdot 4\pi R^2 = -4\pi R^2 \sigma \; Q/(4\pi R^2 \varepsilon \varepsilon_0) = -\sigma / \varepsilon \varepsilon_0 \cdot Q$$

Where Q is a charge of a sphere, E-electric field strength near a sphere, R is its radius, σ is electric conductivity of a medium around a sphere , ε is its dielectric permittivity, and $\varepsilon 0$ is dielectric permittivity of vacuum. Analysis of solids [Nerpin, S.V., Chudnovskyi, A.F.: Soil Physics. Nauka Publishers. Moscow. 1967.],

show that the leakage process time greatly varies from 0.3 ÷ 3·10^3 s in case of dry solids to ·10^-7-10^-6 s in case of humid solids. So the whole process of BL formation has to take place in dry solids.

BL Theory

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BL cover.

Let us write a condition of BL surface stability accounting that its surface represents a thing layer of SiO_2 or Al_2O_3 . Pressure balance equation describing the surface layer compression under action mainly of polarization compression and Coulomb expansion:

$$P_{cover} + P_{atm} + \frac{2 \cdot \sigma_k \cdot k \cdot a \cdot q}{R^3} = \frac{k \cdot q^2}{8 \cdot \pi \cdot R^4} + P_{gas}$$

here *P atm* is atmospheric pressure, *Pcover* is pressure which can keep the cover layer, *Pgas* is pressure of gases captured inside BL at its formation and appearing in chemical reactions during its lifetime. The third term to the left corresponds to polarization compression. The first term to the right described Coulomb pressure of charges acting the surface. σk is a charge of the surface unit, k=(4 $\pi \cdot \varepsilon \varepsilon 0$)^-1, *a* is the layer thickness in general case its value decreases with temperature $a = a_0 \cdot (T/T_0)^{-\alpha}$, where $\alpha>0$. σk is a charge of the surface unit

$$R \approx \frac{q}{16 \cdot \sigma_k \cdot a}$$

For example, at the cover oxide SiO_2 and Al_2O_3 layers thickness of a =0.4 mm and σk ~1.6 C/m^2 one gets $R \approx 1$ m at q=10^(-2) C. However this value is only a tentative estimate obtained at many simplifying suppositions.

BL theory

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BL lifetime.

BL lifetime is determined by time of combustion of metallic powder material of BL. We could not find necessary data for Si from literature, so we use data for combustion of Al powder in conditions at low concentrations of oxygen in the volume [Pohil]. The radial combustion velocity of Al powder is *Vcom*= 5-10 mm/s.

So the estimate for BL lifetime can be ~ 75-150 s, which well fits to observed lifetime of large BL.

Recombination of charges in BL surface with charges of the opposite sign – ions of air. It is the process of the charge Q decrease on a surface of the sphere where to the area $4\pi R^2$ come atmospheric ions:

$$\frac{dQ}{dt} = -4\pi R^2 w N_i e = -4\pi R^2 b_i E \cdot N_i e = -4\pi R^2 b_i \cdot N_i e Q/(4\pi R^2 \varepsilon \varepsilon_0) = -b_i \cdot N_i e Q/\varepsilon \varepsilon_0$$

$$\tau = \varepsilon \varepsilon_0 /(b_i e N_i) \qquad N_i \approx \sqrt{S/\alpha} \qquad \tau = \varepsilon \varepsilon_0 / b_i \cdot \sqrt{\alpha / S}$$

Mean value of ion mobility *bi*= 2.8 10-4 $m^2/(V\ s)$, coefficient of ion-ion recombination in air alpha = 2 10^{-6} cm^3/s , *S* = 4 cm^{-3} s^{-1} . Inserting these values one gets $\tau \approx$ $1.4 \cdot 10^2$ s.

BL theory

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Electric properties. In order to explain of BL in air we accept a mechanism of levitation. For levitation this ball has to satisfy to balance of forces of BL attraction to earth by gravitation and image forces and repulsion in electric field of earth. The uncompensated charge of BL defines a levitation capability of the charged ball. For example in the external field of earth *Eext* a balance of indicated forces acting the charge ball has a form

$$q \cdot E_{ext} = m \cdot g + \frac{q^2}{16 \pi x^2 \varepsilon \varepsilon_0} \qquad (2)$$

where *q* is a charge of the ball, *g* is acceleration of free fall, *x* is a distance between BL and earth surface (we consider that the charge of the ball coincides with the sign of earth charge). For using of (2) one should know a value of *Eext* and *x* in considering conditions. For estimates let us accept *x*=10 m equal to a height of a not tall tree. And the external electric field value under the cloud can be estimated as the field under the charged sphere

$$E_{ext} = \frac{q_{cl}}{4 \pi H^2 \varepsilon \varepsilon_0}$$

where H is a height of the cloud over earth and *qcl* is a charge of the cloud. Usually *qcl*~ 10 C. (in this situation we accept that negative charge already went to earth and the cloud left positive. We consider heavy rainy conditions with level H=500 m. At these parameters one gets a following value of external electric field over earth *Eext* ≈3.6·10^5 V/m.

The electrical charge of the ball of the mass m ≈ 140 kg obtained with a help of the equation (2) is *q*≈9.8·10-3 C.

At this charge value a pressure of charges of BL on its surface is

$$P_{ch} = \frac{q^2}{4\pi \cdot \varepsilon \varepsilon_0 8 \cdot \pi \cdot R_{sph}^4}$$

where *Rsph* is a radius of BL. For the considered BL this pressure proves to be ≈ 0.11 MPa, i.e. it is smaller than the tensile strength of Al_2O_3 and SiO_2 films, and the BL cover will easily stand this pressure.

Knowing the BL charge one can calculate its electrostatic energy

$$W_{el} = \frac{q^2}{2 \cdot 4\pi \cdot \varepsilon \varepsilon_0 R_{sph}}$$

which appears to be rather high, ≈ $6 \cdot 10^5$ J, but considerably smaller than BL chemical energy.

Concerning electrostatic properties of BL one can calculate BL electric field strength on its surface

$$E_{surf} = \frac{q}{4\pi R_{sph}^2 \varepsilon \varepsilon_0}$$

This equation gives = $1.6 \cdot 10^8$ V/m. This is a large value and is greater than the breakdown value of air $E_{br} \sim 3 \cdot 10^6$ V/m.

BL Theory

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Electric field distribution. **The electric field strength distribution over the radial direction at plasma absence is decreasing as**

$$E_0(r) = E_{surf}\,(R_{sph}/r)^2$$

,

and in the region between *R*= *Rsph* and *R*(*E*=*Ebr*) an appearance of a plasma has to be realized over BL surface in the result of ionization, attachment, recombination and other elementary processes [101,102]. In this case there has to appear plasma region which impacts the electric field of the charged ball decreasing it.

$$E(r) = \frac{q}{4\pi\,\varepsilon\,\varepsilon_0 \cdot r}\, e^{-r/r_D}\left(\frac{1}{r} + \frac{1}{r_D}\right)$$

According to [101-102, 104] at appearance of a charge *q* in spatially homogeneous plasma with temperature of electrons *Te* and ions *Ti* there appears a field over the charge:

$$r_D^2 = \left(\varepsilon\varepsilon_0 \cdot k_B / e^2\right)\cdot\left(\frac{N_e}{T_e} + \frac{Z_i \cdot N_i}{T_i}\right)^{-1} \qquad \textbf{(10)}$$

,

where , *kB*- Boltzmann constant, *Ne, Ni* concentrations of electrons and ions, *Z*i -ion multiplicity. Which is reduced to

$$r_D = \left(\frac{\varepsilon\,\varepsilon_0\,T_i}{e^2\,N_e}\right)^{1/2}$$

at *Z*i=1, *Te*>>*Ti*, *Ne*=*Ni*. From (6) it is easily seen That at presence of plasma the field is greatly decreased. This plasma is characterized by electron temperature *T*e > 1.5 eV and ion temperature *T*i > 0.5 eV concentrations of electrons *N*e >10^16 cm-3. According to [101-102,104] electrons and ions of plasma create a layer in the region between *E*surf and *Ebr* with local fields directed oppositely to electric field of the sphere and decrease the initial field of the sphere to the level below the breakdown field value. After that the plasma decays and initial electric field is restored. An the whole the process repeats The distance at which the local field decreases, the Debye radius is ~5.0^·10-6 cm, and a time of the initial field switching off is about of a time of the plasma frequency $\tau_p = \omega_p^{-1} = (4\pi\, e^2 N_e / m)^{-1}$ **~7·10^-13 s (where *m* is electron mass).**

Now let us consider in a simplest approximation processes in air plasmas in this region. One can write continuity equations for electrons and ions at high electric fields when attachment and detachment processes become unimportant in air plasmas:

$$\frac{\partial N_e}{\partial t} - div(D_e \; grad \; N_e) - div(N_e \, b_e \cdot E_0) - div(N_e \, b_e \cdot E_1) = \nu_i \cdot N_e - \alpha_{dr} \cdot N_e \cdot N_i$$

$$\frac{\partial N_i}{\partial t} - div(D_i \; grad \; N_i) + div(N_i \, b_i \cdot E_0) + div(N_i \, b_i \cdot E_1) = \nu_i \cdot N_e - \alpha_{dr} \cdot N_e \cdot N_i$$

where *t*- time, *D*e, *D*i – diffusion coefficients of electrons and ions, *b*e, *b*i – mobilities of electrons and ions, - electric field created by the ball, - electric field created by charges of the plasma.

BL Theory

MSU

At small times influence of charges motion is negligible with respect to an ionization; a recombination is slow with respect to ionization, so a growth of electrons and ions takes place as

$$N_e = N_{e0} \cdot \exp(\nu_i t)$$

where *N*e0 is starting electron concentration.

Let us make all the following estimates for the electric field strength close to 30 kV/cm, i.e close to breakdown parameters. We consider that at higher values of electric field takes place sharp rise of electron and ion concentrations and quasi-neutrality is realized. The ionization times and creation of electrons prove to be of an order of

$$\tau_i \sim 1/\nu_i = 1/(N \cdot k_i) \sim 1/(3.0 \cdot 10^{19} \cdot 10^{-11}) = 3.0 \cdot 10^{-9}\ \mathrm{s},$$

From (11a) one has that at switching off of the electric field plasma decay occurs

$$N_e = N_{e0} \cdot (1 + \alpha_{dr} \cdot N_{e0} \cdot t)^{-1}$$

α~ 2.6·10^-8 cm^3/s, i.e. the recombination time at *N*e0~ 1.0·10^16 cm^3 is ~ 3·10^-9 s .

BL Theory

MSU

Let us consider the case when plasma becomes developed, or satisfies the relation

$$\nu_i \cdot N_e \sim \alpha_{dr} \cdot N_e \cdot N_i \sim \alpha_{dr} \cdot N_e^2 \qquad \text{or} \qquad N_e \sim \nu_i / \alpha_{dr}$$

For conditions of air plasmas at breakdown fields this gives *N*e ~ 1.0·10^16 cm3. For this case let us modify equations (11), considering that variation of charged particle concentrations is slow $\frac{\partial (N_e - N_i)}{\partial t} \sim 0$

It takes a form

$$D_i \, grad \, N_i - D_e \, grad \, N_e - (N_i \, b_i \cdot + N_e \, b_e) \cdot \overline{E}_0 = (N_i \, b_i \cdot + N_e \, b_e) \cdot \overline{E}_1$$

or with accounting that *N*i, *N*e =0 at *R*(*E*=*Ebr*) , and *D*e>>*D*i, *be*>> *bi* one has

$$\frac{-D_e \, grad \, N_e}{N_e \, b_e} - \overline{E}_0 = \overline{E}_1$$

or accepting that there is no sharp jumps of charged particle concentration one has

$$E_0 = E_1$$

BL Theory

MSU

So from the consideration of the problem the distribution of the electric field in case of plasma realization is the following:

*R*sph<*R*< *r*D ,

$$E(r) = \frac{q}{4\pi\varepsilon\varepsilon_0 \cdot r^2} e^{-r/r_D}$$

*r*D <*R* < *R*(*E*=*Ebr*)

E(r)=0;

R> *R*(*E*=*Ebr*)

$$E(r) = E_{surf}\,(R_{sph}/r)^2$$

The frequency of electric field pulses is ν ~ 10^9 s-1 in the area between *R*= *Rsph* and *R*(*E*=*Ebr*), further the field acts in a usual way. Presence of such a pulsed field can explain a luminescence of lamps with cut wires.

Luminescence. At burning combusting metallic particles emit radiation that ensures luminescence of BL. Let us calculate a mass of material necessary to ensure radiation by burning inside BL. For this purpose we apply a following equation describing radiation of solid particles

$$\sigma_{SB} \cdot T^4 \cdot 4\pi \cdot R_{sp}^2 \cdot \tau_{BL} = m \cdot \Delta Q$$

where σSB is the constant of Stephan-Boltzmann, m is mass of metal and τ *BL* is BL lifetime. For the considering case m≈44 kg, or *m*<<*mSi* . So BL can irradiate light at that it have left enough of material for following explosion. Considering the layer *R*sph<*R*< *r*D we can calculate effect of electric field on heating of the surface accepting that all the released discharge energy goes to a heating of the surface. It this case the temperature of the surface is determined by discharge surface and radiation cooling of the surface, or

$$\sigma_{SB} \cdot T^4 \cdot 4\pi \cdot R_{sp}^2 \cdot \approx \overline{\overline{J}} \cdot \overline{\overline{E}} \cdot 4\pi \cdot R_{sp}^2 \cdot r_D = e \cdot \overline{\overline{N}}_e \cdot \overline{\overline{w}}_{dr} \cdot \overline{\overline{E}} \cdot 4\pi \cdot R_{sp}^2 \cdot r_D$$

averaged over time values of a current density, electric field strength, concentration of electrons and drift velocity of electrons in the Debye layer over the ball, respectively, e- electric charge, means

$$\overline{\overline{Y}} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} Y \, dt$$

At that the main rise of temperature takes place during plasma decay during recombination. One gets an estimate temperature of the surface without accounting processes of combustion in the ball

$$T = (e \cdot \overline{\overline{N}}_e \cdot \overline{\overline{w}}_{dr} \cdot \overline{\overline{E}} \cdot r_D / \sigma_{SB})^{1/4}$$

Which for the considering case when during 6·10^-9 s electric field changes from 3·10^6 to 100 V/m, electron concentration changes from 10^16 to 100 cm^-3, and drift velocity - from 2·10^7 to 2·10^5 cm/s gives *T*~860 K. So the oxide cover will not be burnt through but addition of energy from internal part of the ball can lead to its melting. This process realizes additional luminescence of BL surface. It can also cause burns of people and fires.

BL Surface

MSU

At typical temperatures of hot material of the BL cover, organic materials 400-600 K, inorganic materials 1200-1500 K a thin heated layer appears near BL surface in the result of a convection its thickness is estimated as

$$L \sim 2R_{sph} / \sqrt{\mathrm{Re}} = 2R_{sph} / \sqrt{u \cdot 2R_{sph} / \nu_d}$$

Re- Reynolds number, *u* –air velocity, ν_d - dynamic viscosity (ν_d=0.15 cm^2/s for air at a room temperature). At BL radius R =0.5-25 cm, wind velocity (in quiet conditions) *u* = 1 - 10 m/s one gets *L*~0.1-0.3 cm. i.e. temperature drop in this layer does not allow to an observer to detect high temperature of the surface.

Features

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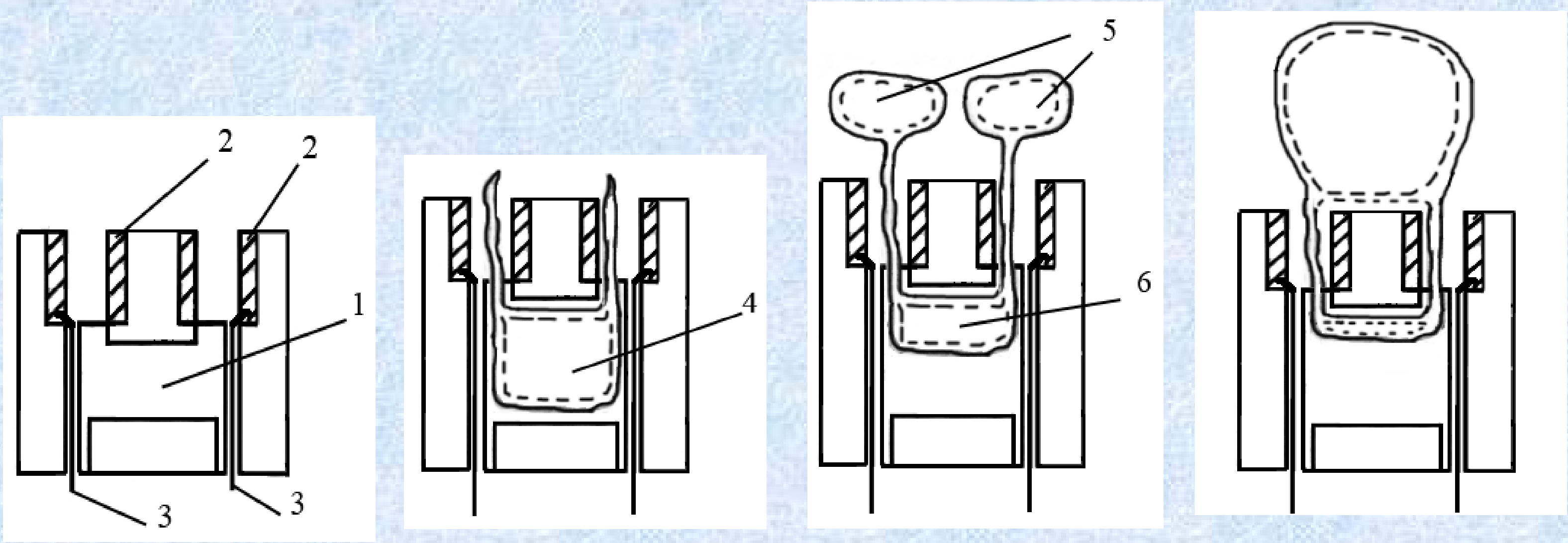
Let melted drop has appeared at electrical short circuit in a cavity in the socket, and then it began to move, then Bernoulli equation for it has a form

$$P_1 = P_2 + \frac{\rho \cdot V_2^2}{2} \qquad V_2 = \sqrt{2P_1 / \rho}$$

At its high velocity a cavity can appear in it , for plastics V2~12 m/s, for Al V2~8,5 m/s

Let a potential F~ 5 10^ 6 V is realized on a wire in the socket in the result of overvoltage wave, then melted bubble has appeared, its blowing out of the socket is represented below. Metal bubble realized in the cavity with radius ~0.01 m Q~5 10^ - 6 Cu will grow (*) to radius of R~0.1 m

F=const on conducting surface



Thank you for attention